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MINISTRY OF SUPPLY

# ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT





PROPULSIVE MUNITIONS DIVISION



## A.R.D.E. MEMORANDUM (P) 31/56





## Guns Using Liquid Propellants

Progress Report No. 4 for the Period

1st January to 30th June, 1956



A. M. Goodall



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1st January to 30th June, 1956

A. M. Goodall (P.1)

Summary

Progress in all branches of the project during the period is reported.

The investigation of the problem of the bulk loaded mono-propellant gun continues to engage almost all the available effort. Programmes of firings in large guns are still in progress, experimental apparatus is being developed as required, and the long-term investigations into toxicity, sensitiveness, logistics, etc. continue.

Difficulty in obtaining ballistic regularity is causing concern. Wherever possible, future work will be directed towards the attainment of better reproducibility.

Approved for issue:

D. H. Chaddock, Principal Superintendent
"P" Division

CONTENTS

| | | Page |
|---|---|---|
| 1. | Introduction | 1 |
| 2. | Bi-Propellant tank gun | 1 |
| | 2.1 Experimental 20 pr. injector gun | 1 |
| | 2.2 Closed vessel firings | 2 |
| 3. | Internal ballistic research | 2 |
| | 3.1 Introduction | 2 |
| | 3.2 I.C.I. Ltd. Programme | 2 |
| | 3.2.1 17 pr. bulk loaded gun | 2 |
| | 3.2.2 Primer experiments | 4 |
| | 3.2.3 Spark ignition | 4 |
| | 3.2.4 Ballistic analysis | 4 |
| | 3.2.5 Conclusion | 4 |
| | 3.3 A.R.D.E. Programme | 5 |
| | 3.3.1 Transparent-chamber firings | 5 |
| | 3.3.2 Travelling-charge gun | 5 |
| | 3.3.3 77 mm gun firings | 7 |
| | 3.3.4 17 pr. bulk loaded gun (A.R.D.E) | 9 |
| | 3.3.5 30 mm research gun | 10 |
| | 3.3.6 Spark ignition | 10 |
| | 3.3.7 Gas snatching device | 11 |
| | 3.3.8 20 pr. bulk loaded slave gun | 11 |
| | 3.3.9 Ballistic analysis | 12 |
| | 3.4 Co-ordination | 12 |
| 4. | Handling, storage and stowage of liquid propellants | 13 |
| | 4.1 Logistics | 13 |
| | 4.2 Engineering of supply | 13 |
| | 4.2.1 Corosion Testing | 13 |
| | 4.2.2 Fighting vehicle design | 14 |
| | 4.2 Toxicity | 14 |
| | 4.4 Sensitiveness | 14 |
| | 4.4.1 Sub-Committee on safety and vulnerability | 14 |
| | 4.4.2 Theoretical Study | 15 |
| | 4.4.3 Testing machines | 15 |
| 5. | Air to air gun | 15 |
| 6. | Attendance at conference | 15 |
| 7. | Discussion and assessment | 15 |
| 8. | Bibliography | 16 |

Illustrations

Fig. 1 - I.C.I. Ltd. Experimental Bursting-Disc Primer in 17 pr. Cartridge Case.
Fig. 2 - General View of L.P. "Travelling Charge" Gun (Assembled in Workshops).
Fig. 3 - "Travelling Charge" Gun. Close-up view of breech with shot and empty igniter tubes.
Fig. 4 - Typical results of 77 mm gun firings with pressure/time curves.
Fig. 5 - 20 Pr. bulk loaded slave gun.

## IMPORTANT

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## PREFATORY NOTE

This report was prepared in June, 1956, for presentation to the Mutual Weapons Development Team of the United States Mission to N.A.T.O.

Acknowledgments are due to a number of collaborators in the project, too numerous to mention individually, for contributions on their own branches of their work.

## 1. INTRODUCTION

Progress is reported for all parts of the project on which work was done during the period. Wherever possible, references are made to corresponding passages in the previous reports, the references being preceded by (R1), (R2) or (R3), indicating the first, second and third progress reports, or (S) to denote the Statement of the Position at 1st July, 1954.

## 2. BI-PROPELLANT TANK GUN (Reference (R3) 2)

### 2.1 Experimental 20 pr. injector gun

This gun was fired three times during January. Each injector port had been increased in area from 4.8 to 13.6 sq. in. on the recommendation of Experiment Incorporated in an attempt to ensure better mixing and so to increase the performance of the gun. This modification also had the effect of increasing chamber capacity from 190 to 270 cu. in. Adjacent injectors were used and the other conditions were similar to those of firing No. 6, except that a larger initiating charge was used to give the same initiating pressure in the enlarged chamber, and improved seals were fitted to the injectors.

Two identical rounds were first fired, using an 8.9 lb shot, followed by a third round with a 20 lb shot.

These rounds were more fully instrumented than any other liquid propellant rounds hitherto. Records were taken of pressure in the chamber, at 6 in. and 66 in. shot travel and at the muzzle, and in addition of both oxidant and fuel pressuresand piston velocities. A pin gauge was inserted in the bore at 120 in. shot travel. Summarised results together with those for rounds 6 and 7 are as follows:-

| Rd. | Date | Shot Weight lb | Chamber Pressure tons/sq.in. | Muzzle Velocity ft/sec | Percentage of propellant reacted at shot exit |
|---|---|---|---|---|---|
| 15 | 12.1.56 | 8.9 | 5.3 | 2527 | 64 |
| 16 | 19.1.56 | 8.9 | 4.8 | 2459 | 60 |
| 17 | " | 20 | 7.3 | 2027 | 63 |
| 6 | 23.7.54 | 8.9 | 1.8 | 1330 | (about |
| 7 | 20.8.54 | 8.9 | 1.9 | 1357 | ( 15 |

Comparing rounds 6 and 7 with 15 and 16 it is apparent that the reaction delay had been greatly reduced in the latest firings, and the improved ballistics reflect a higher percentage of propellant reacted. The results are not so good as these of Round 10 when single-orifice injectors of the same total area were used in opposing injectors, and 70% of the propellant reacted.

Round 17 was fired with a 20 lb shot in an attempt to get a higher proportion of the propellant reacted during the longer time required for the heavier shot to travel up the bore. Although the time in the bore increased from 12.4 to 15.5 m sec, the fraction of propellant reacted at shot exit remained about the same. The rate of reaction fell off rapidly after the end of injection and a much more efficient mixing process during injection would be required if the optimum performance were to be achieved from this gun.

The effect of the improvements in sealing was most marked. After these firings the gun was mechanically perfect and would have gone on firing after changing two neoprene O-rings which were slightly attacked by acid.

A full report on these firings is now in preparation. The gun has been handed over to the Royal Military College of Science for educational purposes, and the supply equipment put into preservation in readiness for further use on monopropellant guns.

2.2 Closed Vessel firings (Reference (S) 2.4.2).

A full record of all the work which was done in connection with these firings is contained in a report now in course of publication at A.R.D.E. It is shown that a considerable amount of information on bi-propellant systems may be gained with relatively little effort on a small scale. Experimental techniques for this novel problem have been evolved, and if the need arose it would be a comparatively simple matter to extend the interesting results already obtained.

## 3. INTERNAL BALLISTIC RESEARCH

3.1 Introduction

The work under this heading comprises the various programmes of firings in bulk-loaded mono-propellant guns, the related experiments on ignition and similar topics, and the processes of formulating a satisfactory ballistic theory from the results obtained.

This work is distributed between I.C.I. Ltd. and various branches of the A.R.D.E. but is co-ordinated.

3.2 I.C.I. Ltd. Programme

3.2.1 17 pr. bulk loaded gun

Nearly 200 rounds have been fired from this gun during the period, the charge in each case being about 6.8 lb of iso-propyl nitrate. The I.C.I. bursting-disc primer was used for ignition, the primer heads being modified by fitting a 3-in. diameter steel flange, the purpose of which was to form a firmer base to the chamber than was provided by the wax filling, so that the position of the venting holes could be more accurately fixed. A diagram showing the primer in the cartridge case is given at Fig. 1.

The more important results from the earlier series of the period include the following:-

(i) In primers with three, two and one holes, venting radially at a position $\frac{1}{2}$-in. forward of the base, 3-holed heads gave the best controlled ignition, the double and single holes producing a marked loss in muzzle velocity and rise in pressure.

(ii) On increasing the diameter of the three holes to 3/16 and 1/4 in. the initial peak pressure rose to 26 tons/sq.in. and muzzle velocity fell by 300 and 400 ft/sec respectively.

(iii) The distance of the venting holes from the base was very critical; for example, primers with holes $\frac{1}{4}$ in. from the base, instead of $\frac{1}{2}$ in., produced misfires and long hang-fires.

(iv) When the venting holes were inclined at various angles to the radial plane, muzzle velocity was unaffected up to 30°, but ignition became uncertain at 60°.

(v) The primer was tested over a wide temperature range, using a 3 lb propellant charge and proved satisfactory from -20°F to +90°F.

(vi) The use of a sponge-rubber pad behind the shot was found to lower the initial peak pressure by about 2 tons/sq.in. when firing charges of about 3 lb weight, but with the 6.8 lb charge it had the effect of increasing the pressure by 2 to 3 tons/sq.in. The use of the pad was abandoned later in the trials.

A further series of experiments was then conducted in which the primer bursting pressure was varied from approximately 2.3 tons/sq.in. to 0.5 tons/sq.in., the criteria for these experiments being the production of flat-topped pressure curves, of high pressures compatible with gun strength, and of low rates of initial pressure rise and good regularity. The majority of the pressure/time traces hitherto obtained in these firings exhibited a double peak instead of being of the usual form of gun pressure curve.

The principal results from this series may be summarised as follows:-

(i) When the primer bursting pressure was reduced from 2.3 to 0.5 tons/sq.in., there was a general tendency for pressure, rate of pressure rise and muzzle velocity to fall, and for the initial pressure peak to become less sharp and more rounded.

(ii) The position and inclination of the venting holes was found to exert a considerable influence on the shape of the pressure/time curve by modifying the contour of the first and second peaks and of the trough between them. It was found that as regards muzzle velocity, gun efficiency and flatness of the pressure/time curve the best angle was $45^{\circ}$.

(iii) The presence of an ullage bubble of up to 3% of the volume of propellant reduced the initial rates of pressure rise. Muzzle velocity increased to a maximum as ullage was increased from zero to 2%, but decreased when ullage was further increased to 3%.

In the course of these trials about 50 rounds were fired with copper-banded steel proof shot of weights between 10 and 17 lb, as part of an investigation into the effects of size of ullage, gun elevation on ullage, variations in shot weight and method of crimping. The most significant result from these firings was the poor reproducibility obtained in groups of identical rounds. Pressures varied by as much as 10 tons/sq.in. and velocity spreads of up to 400 ft/sec were recorded.

The inference was that the shot-start conditions were critical and that at least two things were essential to the achievement of regularity, viz:-

(i) The base of the shot must be sealed against the passage of gas or liquid, e.g., by means of a tightly fitting neoprene sealing ring. *

(ii) The driving band must be firmly in contact with the rifling before firing and free travel must be eliminated. *

Rounds were then fired with these copper-banded shot fitted with sealing rings and not crimped into the cartridge case. Projectiles of 10, $13\frac{1}{2}$ and 17 lb weight were used and reproducible results were obtained. Some flattening of the pressure curve was observed. The general tendency was for both mean pressure and initial rate of rise to increase with shot weight. *

Gun efficiency, i.e. the projectile energy per unit mass of propellant, increased distinctly with shot weight, and, when 17 lb. shot were used, exceeded the performance of service cordite rounds by some $2\frac{1}{2}$% at comparatively low maximum pressures of 20 to 23 tons/sq.in. Typical results for a few of the rounds fired in these series are tabulated on page 6.

### 3.2.2 Primer Experiments

Experiments were made with a primer composition based on copper oxide and titanium which had given excellent results in a small test gun. It was found, however, that with the bursting disc primer, ignition of this compound was difficult, probably because of the cooling effect of the diffusion head and the distance the products had to travel before meeting the propellant.

Suggestions were made for the use of chromium oxide as a catalyst in pyrotechnic compositions for igniting iso propyl nitrate. Experimental quantities of G.12 black powder were therefore prepared incorporating small percentages of ammonium dichromate. It was found that when a composition containing 5% ammonium dichromate was used in primers bursting at about 0.9 tons/sq.in. and venting forward at about 45° from an advanced position, ignition was obtained, whereas black powder alone failed to ignite under the same conditions.

### 3.2.3 Spark Ignition (Reference (R3) 3.1.9 and 10)

A novel low-tension system has been designed and made. The device consists of a low-voltage circuit with the electrodes initially in contact and surrounded by propellant. On firing, a very heavy current is passed and at the same time the electrodes are separated to produce an arc discharge. Separation of the electrodes can be done either by withdrawing one electrode from its contact within the chamber or by advancing it further into the chamber. The latter method has the advantage that it may be utilised to apply pressure to the propellant and so facilitate ignition. Only the former method has, however, yet been tested, and only under laboratory conditions.

### 3.2.4 Ballistic Analysis

Some progress has been made by I.C.I. Ltd. in the formulation of a ballistic theory for the liquid propellant gun. In a hypothesis due to D.A. Stewart the equations of motion and state are used in their normal form, but the equation of continuity is modified by the introduction of a term representing the continuous conversion of liquid propellant to gaseous products by decomposition. To simplify the calculations it is assumed that the heat losses are small, so that an approximate relation between pressure and density can be used. From the experimental pressure gradients the acceleration, and hence the velocity of each element of gas, can be calculated. By substitution of the values of gas velocity and density in the continuity equation the amount of liquid burnt in any element of space during any time interval can eventually be arrived at. Special arrangements will be necessary for carrying out the laborious computation required, and also to provide instrumentation for a large number of pressure readings in guns.

### 3.2.5 Conclusion

From the work so far done, I.C.I. Ltd. conclude that a fair measure of control can be obtained with bulk-loaded iso-propyl

nitrate rounds by suitable design of pyrotechnic primer. The indications so far are that the primer should be a self-contained unit in which, to ensure regularity, burning is partly completed before the products are injected into the propellant. The pattern of injection of the primer gases into the liquid can be determined by fitting suitable injection heads to the primer. The pressure characteristics of rounds of this kind can be controlled by the position and pattern of venting. It appears at present that injection at a point near the base of the chamber with vents inclined forward, gives the best performance, with flattish pressure/time and pressure/space curves. With the size of chamber so far used (approximately 3 litres capacity) vents inclined at 45° are found to give the most satisfactory results.

The experiments have already shown the advantage in improved gun performance that is to be gained from the use of liquid propellants. Greater projectile energy per unit mass of propellant has been obtained with iso propyl nitrate than with cordite, at lower pressures and despite the fact that the relative energy contents of the two are as 50 to 70 respectively.

Reports covering the work done during the first half of this period and the second half of the preceding period have been issued by the firm (1) (2).

3.3 A.R.D.E. Programme

3.3.1 Transparent-chamber firings (Reference (R3) 4.1)

A number of further firings were carried out in order to observe the phenomena of ignition. In one experiment a $\frac{5}{8}$ in. thick steel tube with a number of "portholes" cut in it was fitted over the normal $2\frac{1}{2}$ in. Perspex tube in an attempt to provide additional strength. The tube was filled with nitro methane and fired with a No. 32 primer. The tube burst violently, but the pressure record showed that the effective strength had been greatly increased. Arrangements are now being made to conduct a similar experiment in a 2 pr. (40 mm) gun, by drilling holes in the chamber and loading the charge in a Perspex cartridge case. As the service equipment does not lend itself for the purpose, the design of a specially simplified breech ring and mounting is under consideration. In the meantime the transparent-chamber apparatus is being modified so that a smooth-bore barrel may be fitted as an extension to a $1\frac{1}{2}$ in. diameter transparent tube and a projectile fired.

A number of firings which have been made with $1\frac{1}{2}$ in. bore transparent P.V.C. tubes show that this material has considerable promise.

3.3.2 Travelling-Charge gun

This device, which consists of a $\frac{1}{2}$-inch bore gun with a very long barrel, was constructed in order to study a suggestion that in a liquid propellant gun an increased muzzle velocity is possible since a part of the charge travels down the bore with the shot, burning immediately behind it. Photographs of the gun are shown at Figs. 2 and 3. The barrel is built up from a chamber portion and three 30-inch lengths of tube which screw together to provide the maximum shot travel of 90 inches. Two sections or one section of the tube may be used alone with the chamber if desired.

I.C.I. Ltd. Nobel Division

Development Tests in 17-pdr. Gun with Isopropyl Nitrate as Monopropellant

| Round No. | Description | Shot Wt. lb | Charge Wt. grammes | Pmax. Tons/sq.in. | M.V. ft/sec |
|---|---|---|---|---|---|
| 320 | 45° head, point of injection 13/16" from chamber base. Bursting pressure 1.5 tons/sq. in. Primer charge = $22\frac{1}{2}$ g of G.12 Rubazote pad $3"x4"x\frac{1}{2}"$ on side of cartridge case simulating a natural ullage bubble. | 7.02 | 2880 | 23.8 | 4077 |
| 321 | | 7.06 | 2890 | 21.4 | 4066 |
| 322 | | 7.06 | 2890 | 22.0 | 4113 |
| 317 | 45° heads; point of injection 1.5/16" from chamber base. Primer bursting pressure: 0.9 ton/sq.in. Primer charge $22\frac{1}{2}$ g of G.12 | 7.7 | 2995 | 25.4 | 3949 |
| 318 | | 7.7 | 2990 | 26.3 | 3996 |
| 319 | | 7.7 | 2995 | 26 | 3990 |
| 283 | Radial venting; position of injection $\frac{1}{2}$" from base of chamber. Bursting pressure 1.5 ton/sq. in. Primer charge: 15 g of G.12 | 13.48 | 3080 | 19.4 | 2969 |
| 284 | | 13.48 | 3075 | 22.0 | 3020 |
| 285 | | 13.48 | 3035 | 18.8 | 2936 |
| 286 | | 13.48 | 3035 | 18.6 | 2988 |
| 298 | Radial venting $\frac{1}{2}$" from chamber base. Bursting pressure 1.5 ton/sq.in. Primer charge 15 g of G.12 | 16.84 | 3035 | 21.5 | 2733 |
| 299 | | 16.82 | 3015 | 18.2 | 2706 |
| 300 | | 16.79 | 3020 | 23.0 | 2708 |
| 301 | | 16.81 | 3035 | 23.0 | 2784 |
| 308 | 45° venting; 13/16" from chamber base. Bursting pressure 1.5 ton/sq.in. Primer charge: 15 g of G.12 | 16.8 | 2985 | 23.4 | 2822 |
| 309 | | 16.8 | 2975 | 17.5 | 2736 |
| 310 | | 16.8 | 2949 | 22.8 | 2793 |

All rounds:

Cartridge case : 17 pdr. Internal configuration modified by wax filling.
Propellant : Pure iso propyl nitrate
Primer charge : G.12 black powder.

Piezo-electric gauges are fitted to each tube section, as well as to the chamber and muzzle. A vacuum chamber has been provided into which the gun can be fired when necessary.

Two firings were first made with iso propyl nitrate at high ullage, 20 c.c. of propellant in 100 c.c. capacity chamber. The charge was estimated not give an excessive pressure, even if "all burnt" occurred before shot start. The shot was a 4 gramme duralumin slug.

The observed velocity at 20 ft from the muzzle was 4200 ft/s with a 30 in. barrel and 5150 ft/s with a 90 in. barrel. The increase in velocity in the longer barrel is too large to be due solely to further expansion of the burnt gases and indicates that even with very small charges some propellant is burnt in the bore. The second round caused some slight damage to the gun, due to a fault in design.

After repair of the damage, a full-charge firing was attempted. With the 4 gramme shot a charge of 95 grammes of iso propyl nitrate was loaded, ignition being by means of an F85 fuze and 1 gramme of G12 gunpowder in a copper primer tube. After an initial failure, the gun fired at the second attempt and the third barrel section burst about 10 in. from the muzzle, that is after about 80 in. of travel. No satisfactory explanation of this occurrence has been found. The observed velocity was 9100 ft/s over a 10 ft base starting 18 in. from the muzzle.

A few more firings were subsequently made using two barrel sections and a modified breech permitting the use of standard electric primers. The charge was 95 ml. of iso propyl nitrate ignited by the base of a No. 13 electric primer. Firings were satisfactory in that no damage was done to the gun, but muzzle velocities (into air) were disappointingly low, being only of the order of 3000 ft/s with the 4 gramme shot. Pressure/time curves recorded at various points show a very complicated wave pattern which is, however, fairly regular from round to round Further firings with a higher shot-start pressure are contemplated. During a visit to the U.S. in May by A.R.D.E. representatives the opportunity was taken to discuss the results with Experiment Incorporated, who have experience of a similar gun.

3.3.3 <u>77 mm Gun firings</u> (Reference (R3) 4.2.3)

In continuation of the programme to obtain data for formulating an internal ballistic system, about 100 rounds have been fired in this gun during the period, using Service cases full of iso propyl nitrate, No. 11 primers and a variety of shot. Shot weights ranged from $3\frac{3}{4}$ lb to 17 lb and ebonite, nylon and copper driving bands were used.

Regularity of muzzle velocity and reproducibility of pressures were in general fairly satisfactory. Velocities for the $3\frac{3}{4}$ lb and 17 lb shot were 4858 and 2533 ft/s respectively, and pressure/time curves show that there is a tendency for the curve to become increasingly flat-topped as shot weight increases.

A point of some interest is that the service velocities for both APDS (W = 7-14-0, V = 3600) and APCBC shot (W = 17, V = 2700) have been approached with the same charge weight of liquid propellant and at considerably lower maximum pressures.

Results are summarised below:-

Charge 2400 cc IPN ≡ 5.7 lb
Ignition No. 11 primer (6 drams G12).
Ullage about 2%

| Shot Weight lb | Band | Number of rounds | | Mean Velocity ft/s | m.d. ft/s | P max tons/ sq.in. |
|---|---|---|---|---|---|---|
| 3¾ | Nylon | 6 | | 4850 | 26 | 21 |
| 6¾ | Copper | 6 | 850 | 3511 | 33 | 22 |
| 9 | " | 2 | 950 | 3248 | 36 | 18 |
| 11 | " | 2 | | 3053 | 33 | 17 |
| 13 | " | 2 | | 2917 | 14 | 19 |
| 17 | " | 6 | 1090 | 2533 | 36 | 16 |

"P max" figures are rough means of the tops of the humps.

Further series of firings were made using mixtures of various proportions of iso propyl nitrate and nitromethane with 17 lb shot. Ullage was about 2% and ignition was with No. 11 Mk. 3 primers as in previous firings. A few rounds have been fired with 100% nitromethane.

Results are summarised below:-

All rounds: Standard case with about 2% ullage;
17 lb shot, double copper bands.
Primer No. 11 Mk. 3 (6 drams G.12; 8¼-in. holes, 1.4 in. long).

| Round | Charge ml. Ipn | Charge ml. Nm | Pmax (tons /sq.in.) | M.V. (ft/s) | Remarks |
|---|---|---|---|---|---|
| 1 | 2000 | 400 | 22.1 | 2669 | |
| 2 | " | " | 27.2 x | 2726 | |
| 3 | " | " | 23.1 | 2732 | |
| 4 | " | " | 19.6 | 2679 | |
| 5 | " | " | 20.1 | 2667 | |
| 6 | " | " | 34.5 x | 2749 | |
| | | | | (Mean 2704) | |
| 7 | 1800 | 600 | 23.3 | 2707 | |
| 8 | " | " | 20.1 | 2703 | |
| 9 | 1600 | 800 | 20.4 | 2778 | higher |
| 10 | " | " | N.R. | 2845 | |
| 11 | 1200 | 1200 | 23.0 | 2837 | |
| 12 | " | " | 18.4 | 2789 | highest |
| 13 | " | " | 22.5 | 2863 | |
| 14 | " | " | 25.2 | 1858 | |
| | | | | (Mean 2857) | |
| 1 | 1200 | 1200 | 20.2 | 2703? | |
| 2 | " | " | 29.0 x | 2881 | |
| 3 | " | " | N.R. | 2902 | |
| 4 | " | " | 23.0 | 2821 | |
| 5 | " | " | 23.0 | 2849 | |
| 6 | " | " | 20.8 | 2836 | |
| | | | | (Mean 2858) (w/e rd. 1) | |

| | | | | |
|---|---|---|---|---|
| 7 | 800 | 1600 | 27.2 x | 2930 |
| 8 | " | " | 20.3 | 2891 |
| 9 | " | " | 24.2 | 2911 |
| 10 | 600 | 1800 | 37.9 x | 2930 |
| 11 | " | " | 21.9 | 2929 |
| 12 | " | " | 20.9 | 2844 |
| 13 | " | " | 31.9 x | 2943 |
| | | | | (Mean 2912) |
| 14 | 0 | 2400 | 31.0 x | 3071 |
| 15 | 0 | " | 36.5 x | 3162 |
| 16 | 0 | " | 38.4 x | 3159 |
| 17 | 0 | " | N.R. | 3509 Gun damaged |

x - Sharp peak to pressure/time curve. Curves more or less flat-topped in other cases.

Two types of pressure/time curve were obtained with all mixtures of iso propyl nitrate and nitromethane: (a) flattopped and (b) with a sharp initial peak, but the proportion of type (b) increased as the percentage of nitromethane was increased. The general pressure level rose with increased nitromethane and the initial peak became unacceptably high. The last round with 100% nitromethane damaged the gun.

Two more firings were made using iso propyl nitrate and the 17 lb shot. In the first series ullage and igniter were varied. For the ullage firings the cases were modified with beeswax so as to produce a flat base internally; they were filled completely and the amount necessary to give the required ullage extracted. The results showed that 80 ml. ullage gave the best results. A typical series of results from these firings, together with reproductions of the pressure/time curves, are shown at Fig. 4.

For the igniter firings unmodified cases were used with No. 9 primers filled with 10, 20 and 30 grammes of G.12 powder. The 20 gramme igniter gave the best results. On this occasion one round of an ethyl nitrate-butanol mixture was fired with a No. 11 primer. This gave a chamber pressure in excess of 36 tons/sq.in, damaging the gauge and jamming the breech of the gun. This experiment was not repeated.

An attempt was then made to study the effect of combining the condition of ullage and igniter which gave the best results previously, i.e., 80 ml. ullage and No. 9 primer filled 20 grammes G.12, with the additional control of firing at fixed elevation to keep the ullage in the same position. Rounds were fired at 55 minutes elevation, but results were so erratic that a change was made to factory-filled No. 11 primers. 14 more rounds were then fired at 55 minutes elevation, the mean velocity being 2597 ft/s with m.d. 22 ft/s. There was a considerable variation in pressures.

3.3.4 17 pr. Bulk loaded gun (A.R.D.E.) (Reference (R3) 3.2)

Two guns adapted to this design have been delivered, together with the necessary spark ignition apparatus, and one round has been fired from both guns. In each case a charge of about 3 lb iso propyl nitrate was loaded, with $5\frac{3}{4}$ lb nylon-banded proof shot. The chamber capacity was the largest possible, i.e. 79 cu. in.; ignition was through four 3/16 in. radial holes in the primer, near the base of the liquid. The primer contained 17 c.c. of ethyl nitrate.

The first round gave a velocity of 3656 ft/s with a pressure estimated at about 35 tons/sq.in. In the second gun there was a misfire at the first attempt, but on firing the velocity was found to be 3629 ft/s, with approximately the same pressure as before.

The excessively high pressure caused slight damage to both guns and cartridge cases, producing difficulty in extraction. The ejection of gas from the primer was sufficiently fierce to produce local damage to the walls of the cartridge case. The inference is that the system of ignition transfer from the plenum chamber to the main charge was unnecessarily violent, but this conclusion may be premature.

Trials in a 30 mm gun have in fact shown that shot-start conditions may be of considerable importance in this connection. A carefully planned research, aimed at establishing the relative importance of methods of dispersion of ignition energy within the main charge volume, geometry of chamber, ullage, propellant properties and shot-start conditions, appears to be necessary, and some early work along these lines is briefly mentioned in Sections 3.3.5 and 3.3.6 below.

3.3.5 <u>30 mm research gun</u> (Reference (R2) 4.6)

A preliminary set of firings has been undertaken with a number of different propellants using a blow-out disc controlled pyrotechnic igniter, 25% ullage and a standard 30 mm projectile. These firings were made under standard conditions of charge weight and shot weight in order to obtain information on the rate of pressure rise in the chamber. They showed that under the particular conditions of firing, different propellants gave considerably different rates of rise. It must be stressed that these are preliminary results and may later need revision; they do show, however, that differences may be expected. The order of propellants in increasing rates of pressure rise is:-

| | |
|---|---|
| Ethyl nitrate/butanol 91/9 | |
| Isopropyl nitrate | |
| Hydrazine/hydrazine nitrate/water | 57/33/10 |
| " " " " | 54/36/10 |
| Nitromethane/isopropyl nitrate | 34/66 |
| Nitromethane/isopropyl nitrate | 55/45 |

During the firing of the last propellant the gun was seriously damaged and had to be scrapped. A new gun has been mounted and a further series of firings begun, limited in the first place to ethyl nitrate/butanol 91/9. The limitation has been necessary because of a marked difference in the rate of pressure rise in the new gun compared with the gun previously used. For example in 15 firings in the first gun, using a 91/9 mix of ethyl nitrate/butanol, the measured average rate of rise was 290 tons per m sec. Pressure rise curves were reasonably similar in all cases. Trials under precisely similar charge weight, shot weight, propellant, ullage and chamber geometry in the second gun gave reasonably repeatable pressure rises of only 50 tons per m sec over a series of 22 firings. Gun measurements showed that the run-in conditions of the first gun were more difficult than those of the second. Further trials are in progress to establish ullage effects over the range 2% to 33% ullage. The programme of work aimed at providing data on type of propellant effect on rate of pressure rise, is still in its early stages and will be fully reported at a later date.

3.3.6 <u>Spark Ignition</u>

A number of satisfactory electric spark ignition firings have been obtained using a 30 mm gun, but, as reported above, the results in the 17 pr. gun were less successful. To investigate the causes of these failures a spark ignition chamber has been made and tests commenced to indicate the effect of propellant, plenum chamber geometry, spark location, and minimum spark energy required. Tests are being undertaken over a range of initial pressures ranging from atmospheric to 2500 lb/sq.in., and will in due course cover a temperature range from -40° to +160°F.

Work has continued on the development of the liquid propellant igniter. (Reference (R3) 4.4). After damage in firing the design was modified. Further firings have now been carried out, varying the voltage and spark energy for various sizes of the vent hole from the spark chamber to the main body. In the course of the firings difficulty has been experienced on account of enlargement of the vent hole. To overcome this, new end plugs fitted with tungsten carbide inserts are being manufactured, the fine hole being drilled in the insert by spark machining.

3.3.7 <u>Gas snatching device</u> (Reference (R3) 4.5)

Gas analyses have been made by E.R.D.E. on the products from mono-propellants, particularly iso propyl nitrate, burnt in a closed vessel at gun pressures, to enable a comparison to be made between the actual proportions of the products and those calculated from the equilibria.

The results, which are presented in detail in an unpublished paper, show that consistency between the calculated and experimental figures is obtained if a net correction of 10% is made for energy losses and igniter charge. A correction of this order appears reasonable in the light of previous data.

3.3.8 <u>20 pr. Bulk loaded slave gun</u> (Reference (R3) 3.3)

This slave gun, a drawing of which is shown at Fig. 5, is similar to the 20 pr. bulk loaded gun described in reference (R1) 3.3, but differs by being simpler mechanically. The object of the simplification was mainly to make manufacture easier so that a gun could be ready for trial with the least possible delay.

The simplified design will enable attention to be focused on ballistic performance rather than on the functioning of mechanical details. In place of the sliding-block breech closure, which is being developed separately in a conventional gun, there is a simple breech screw and plastic obturator.

As can be seen from Fig. 5, the slave gun retains the important features of the prototype. A flameproof filling valve has been incorporated and the chamber is designed to give a variable length of run-up to the rifled bore.

The gun is loaded by placing the shot just inside the chamber. The breech is then closed and the liquid pumped in. This forces the shot up to a restriction in the plain bore of the chamber liner. The position of this restriction determines the volume of the liquid charge by stopping the forward movement of the shot. In order to ensure that the behaviour of the shot before it reaches the rifled bore is as nearly as possible the same as in the prototype, in which a measured quantity of liquid is pumped in, the resistance offered by this restriction has been kept to the minimum necessary to withstand the force on the shot due to the filling pressure of 150 to 250 lb/sq.in. This method will be used until a satisfactory metering device has been developed, and until then will enable firing trials to be carried out and the effect of various propellants, charge weights, and methods of ignition to be observed.

The gun has recently been proved with solid propellant and preparation for the first firings with liquid are now almost complete.

The experimental pyrotechnic ignition equipment is available and is undergoing test. Propellant metering equipment has been provided and tested in a mock-up barrel and will be incorporated during early firing trials of the slave gun.

### 3.3.9 Ballistic Analysis (Reference (R3) 4.2.5)

The analysis of reproducible results of A.R.D.E. firings in the 77 mm gun has continued. The progress and conclusions drawn so far from this work, which is due to J. A. Booth, are briefly summarised below. A pressure/space curve has been derived by double integration of pressure/time curves and from this the amount of propellant burnt at various shot positions has been found. With a normal Lagrange approximation to allow for pressure gradient the area under the pressure/time curve was about 25% too great for the velocity realised. This was probably due to propellant travelling down the bore behind the shot. By assuming that initially half the propellant was attached to the shot, fair agreement between experiment and theory can be obtained.

As firings progressed better instrumentation facilities enabled more pressures in the bore to be measured. By taking the envelope of p/t curves from chamber and bore, shot base pressures are obtained, and from these a curve connecting fraction of charge burnt with travel can be derived. This was done for a number of rounds and it was found that a linear relationship existed between travel and fraction of charge burnt. Initially an addition of half the propellant weight had been added to the true shot weight in the calculations. As the majority of the calculations were made on rounds in which 17 lb shot had been fired, the true and effective shot weights were fairly close to one another.

From the fact that fraction of charge burnt is proportional to travel, which forms the basis of the theory, it follows that mass rate of burning is proportional to shot velocity. The resulting system makes ballistic prediction possible, although this is at present confined to guns and igniter systems which have been fired at other charges and shot weights. The particular circumstances of an experimental firing are represented by a single parameter. More sophisticated systems introducing a number of parameters are valueless unless each new parameter can be associated with a physical variable whose behaviour is known. It is hoped that experimental firings under a wide variety of initial conditions, including various calibres of gun, will enable the influence of these conditions on the single parameter to be determined and lead to the development of a more ambitious system. The theory does not predict a double-peaked chamber pressure/time curve, but this fact is not thought to be important since there is a considerable amount of evidence that the first peak occurs after only a small shot travel and that the second may be extremely localised in space; further a single-peaked curve can be obtained in practice by a suitable choice of igniter. A full report on this work is in preparation.

## 3.4 Co-ordination

A meeting between representatives of I.C.I. Ltd. and A.R.D.E. was held at I.C.I.'s Nobel Division Research Department, Stevenston, Ayrshire, Scotland, on 22nd March, 1956, with the purpose of reviewing the present state of knowledge on the internal ballistics of bulk-loaded liquid monopropellant guns. No formal agenda was prepared, but the following questions were used as a basis for discussion:-

(i) What evidence exists as to the physical processes which take place?

(ii) Can a qualitative theory be constructed which is in line with the available evidence?

(iii) If such a theory can be constructed, can it be put on a quantitative basis?

It was accepted that direct evidence was provided by the transparent-chamber firings and the pressure/time records of gun firings, and that the variation of observed ballistic phenomena with:-

(a) ignition
(b) shot weight or time scale
(c) propellant
(d) calibre or linear scale
(e) temperature
and (f) ullage

was the main source of indirect evidence. The discussion dealt fully with all the work so far done by I.C.I. and A.R.D.E. and covered a wide variety of topics. It was agreed that the ballistic theory put forward by J. A. Booth, and outlined above, was the first and so far the only attempt to produce a quantitative theory for liquid propellants and formed an exceptionally good basis for further work. It did not, however, lead to any better understanding of the physical processes which occur in the gun on firing. The lack of knowledge of these phenomena was proving a serious obstacle to further progress, and it was clear that all available effort must be devoted to acquiring this knowledge by the full analysis of all significant firings both by existing methods and by any other means which could be devised.

The meeting served a valuable purpose in reviewing the experimental work and in providing a full interchange of views on the whole problem.

## 4. HANDLING, STORAGE AND STOWAGE OF LIQUID PROPELLANTS.

### 4.1 Logistics (Reference (R3) 7.2)

After a carefully planned tour of establishments in the U.K. engaged on the various aspects of liquid propellant work Messrs. Electro-Hydraulics Ltd. have completed a preliminary survey of the problem and a report has been issued (3). The firm's work is being concentrated on the local gun supply at this stage, particularly the assessment of all proposed pumping systems.

### 4.2 Engineering of Supply

#### 4.2.1 Corrosion testing

The testing of sample gun steels has continued, and previously reported satisfactory results with iso propyl nitrate, ethyl nitrate/butanol and nitro methane have been confirmed with the propellants both stagnant and stirred. In all cases other than stirred nitro methane the corrosion rate at 30°C is found to be less than 0.0001 in. per year; with stirred nitro methane the loss was at the rate of .0002 in. per year. These tests were carried out with gun steel specimens only, suspended in the propellant in metallic contact with stainless steel or aluminium, and also suspended in the propellant with the same metals, but not in metallic contact.

Results with the hydrazine/hydrazine nitrate/water mixture were less satisfactory. For gun steel alone the corrosion rates were:-

| | |
|---|---|
| Stagnant | 0.0113 in. per year |
| Stirred | 0.0128 in. per year |

It was found that metallic contact in the stagnant condition afforded some slight protection to the gun steel, whether stainless steel or aluminium were used as contacting metals. A point of special interest was that the gun steel corrosion rate increased in metallic contact with stainless steel and aluminium when the propellant was kept moving by stirring. A report on this work is in preparation.

In general it appears that if propellants are confined to the iso propyl nitrate or ethyl nitrate/butanol series the corrosion problems will be negligible and the use of normal steels should be perfectly satisfactory.

Work on the chromium plating of gun steels to resist the action of red fuming nitric acid (Reference (R3) 2.2) is being brought to a close and the contract with the Ionic Plating Company will shortly be terminated.

4.2.2 Fighting vehicle design

Preliminary discussions have taken place between A.R.D.E and F.V.R.D.E. on the subject of stowage of liquid propellant in the vehicle. If stowage outside the rotating gun platform should prove necessary, the use of a suitably designed and tested rotary base junction will be considered.

The design of pumping equipment within the vehicle is being studied jointly by A.R.D.E., F.V.R.D.E., and Electro-Hydraulics Ltd. For this purpose the two propellant pumps developed by A.R.D.E. and J. & E. Amfield Ltd. (Reference (R1) 6.2) have been made available to the firm for examination, both pumps having now successfully completed shop trials.

4.3 Toxicity (Reference (R3) 7.4.1)

For financial and other reasons it has beennecessary to curtail the programme of investigation originally placed with C.D.E.E., Porton. As the chief interest now centres around iso propyl nitrate and ethyl nitrate/butanol mixtures, hydrazine is to be omitted from the list of substances tested. An extensive literature on this propellant is in any case already available in America. An approach is also to be made to the U.S. Chemical Corps regarding the toxicity of nitro methane.

The problem of toxicity alarms (Reference (R3) 7.4.2) is affected by the decision to study two propellants only, since the toxicity of these liquids, or at least the acute toxic effect, is only of a nature similar to that of gasoline.

Decomposition of these propellants on hot surfaces does, however, lead to increased toxicity due to nitrous oxide concentrations. An infra-red detection and alarm system has been examined in the hope that it could be used for hydrazine and nitrous oxide. In the case of hydrazine, interference by normal water vapour concentrations reduced the sensitivity of the apparatus to the extent that it could not effectively be used. Detection of nitrous oxide is, however, not seriously affected by normal water vapour concentrations, and it is proposed to examine the system further to ascertain its suitability for detection of iso propyl nitrate and ethyl nitrate concentrations.

4.4 Sensitiveness (Reference (R3) 5)

4.4.1 Sub-Committee on Safety and Vulnerability

The Sub-Committee on the Safety and Vulnerability of Liquid Propellants has continued to meet and now has the following terms of reference:-

(i) The study of the risks arising from the introduction of liquid monopropellants for use in guns, in respect of sensitiveness, stability and toxicity.

(ii) To undertake trials as may be required by this Sub-Committee.

Under (ii) it is supervising a series of firing trials which are being conducted jointly by F.V.R.D.E. and E.R.D.E. (Reference (S) 2.5.7). In these trials the monopropellant is contained in a mild steel box made of .064 in. plate, 18 inches square based and 20 inches high, and is attacked centrally by .5-inch Browning bullets through 12 to 14 mm armour plate. Blast gauges are set up round the containers, so that if the propellant explodes the strength of the explosion may be assessed. For the purpose

of calibrating the gauges a bare charge of plastic explosive of known weight is fired statically with a detonator after the first round of a series, the weight chosen being such as to simulate the effects of the liquid propellant firing. The strength of the explosion can thus be expressed in terms of pounds of plastic propellant.

Satisfactory propellants are subjected to a fire risk trial, for which they are loaded into a perspex box and again attacked centrally by .5-inch Browning through armour, the thickness of armour being such as to reduce the shot velocity after penetration to 2400 ft/s. High-speed colour cine-photography of the explosion from the side is arranged for, so that the charge can be seen behind the armour.

The present series of trials covers tests of ethyl nitrate/butanol, nitro methane and 50/50 nitro methane/propyl nitrate.

4.4.2 Theoretical Study

In the meantime the long-term study of this method of assessing sensitiveness has continued at E.R.D.E. and two reports have been issued (4) (5). The results, which will be discussed in a later Progress Report, suggest that the data provided by small-scale projectile attack tests could be more conveniently and accurately obtained by other means, e.g. the "gap" test (Reference (S) 4.17).

On the other hand, it is still not possible to predict the chance of an explosion in a Service container under attack in the field by any other method than full-scale trials.

4.4.3 Testing Machines

The Olin Mathieson impact machine (Reference (R3) 5.1.3 (ii)) has been tested and found to suffer from a number of serious drawbacks. A completely re-designed machine based on the same principle has been giving satisfactory results and a programme of work to set up tables of sensitiveness for a variety of propellants is in hand. A report will be issued shortly.

## 5. AIR TO AIR GUN (Reference (R3) 6).

A full report on the work on test guns has now been issued (6).

## 6. ATTENDANCE AT CONFERENCE.

Mr. J. B. Goode was present as a representative of A.R.D.E. at the 7th AXP Conference held at Washington, D.C., during April, 1956. He presented a paper, (7) prepared jointly by E.R.D.E. and A.R.D.E. on the use of liquid propellants for long-range weapons and in guns. The paper sets out the U.K. views on this subject, and, inter alia, reviews briefly the experimental and theoretical work in progress in this country on the liquid propellant gun project.

## 7. DISCUSSION AND ASSESSMENT.

The investigation of the problem of the bulk loaded monopropellant gun in its various aspects continues to engage almost all the available effort. Programmes of firings in large guns are still in progress, the arrangement and conduct of these trials, in which propellant is loaded into cartridge cases, being relatively straightforward.

The development of special experimental guns and apparatus is somewhat more difficult and is subject to the delays incidental to this type of

experimental work. The subsidiary investigations into logistics, toxicity, sensitiveness, and the engineering work on corrosion and vehicle design are necessarily of an extended nature.

The firing of some hundreds of rounds from 17 pr. and 77 mm guns has now amply demonstrated the general feasibility of the principle of the bulk-loaded gun. But the disturbing feature of the results of these firings is that for given sets of conditions ballistic regularity still appears to be almost fortuitous. It is a common experience to find that groups of apparently identical rounds give widely different values of pressure and velocity. Since there is a choice of an almost endless variety of conditions available in these trials, the dissipation of valuable effort in fruitless experiments must be avoided.

It is obvious that at this stage of the investigation an intensive effort is required to achieve reproducibility, first for given conditions in one gun and eventually over a range of different conditions and gun sizes.

The correlation of these results with a satisfactory theory would naturally follow this step, so that the major parameters which govern the "fired" ballistics can be determined. The pre-requisite to this process is a better understanding of the physical processes of ignition, and, wherever possible, future experiments will be designed with this end in view.

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An Investigation into the Mechanism of the Rifle Bullet and Fragment Attack Tests.
P. C. Hobbins and E. G. Whitbread

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An Investigation into the Pressure History of an Explosive under Projectile Impact.
P. C. Hobbins, E. L. Kendrew, and E. G. Whitbread.

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F. S. Edwards

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G. K. Adams, E.R.D.E. and G. R. Nice and J. A. Booth, A.R.D.E.

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FIG. I.

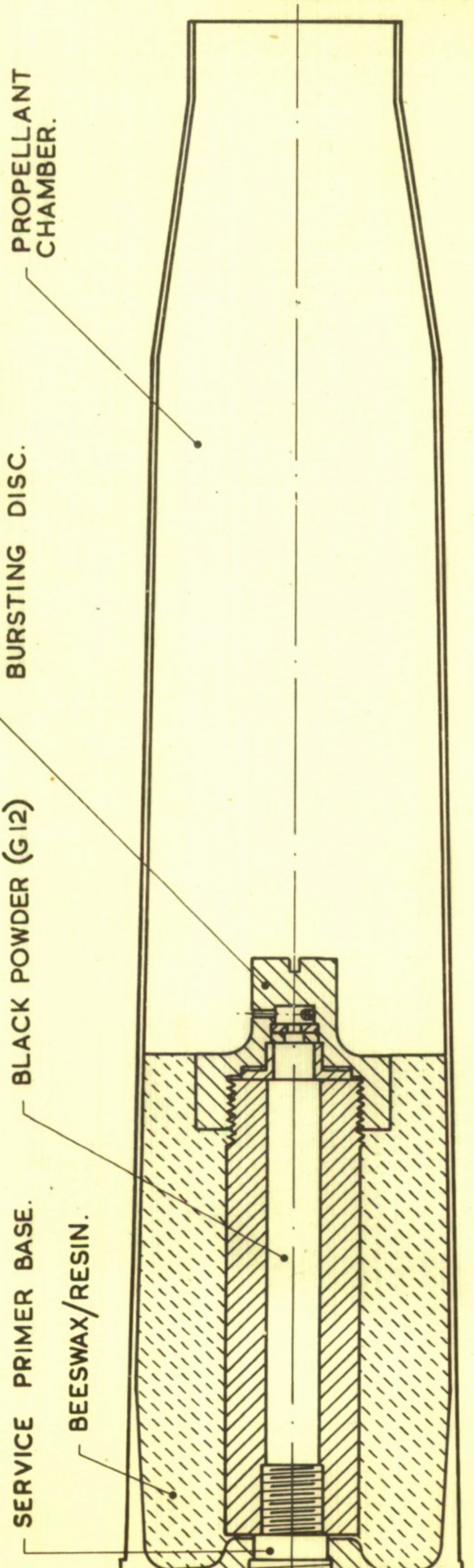


FIG. I. I. C. I. LTD. EXPERIMENTAL BURSTING - DISC PRIMER IN 17 PR CARTRIDGE CASE.

CONFIDENTIAL DISCREET

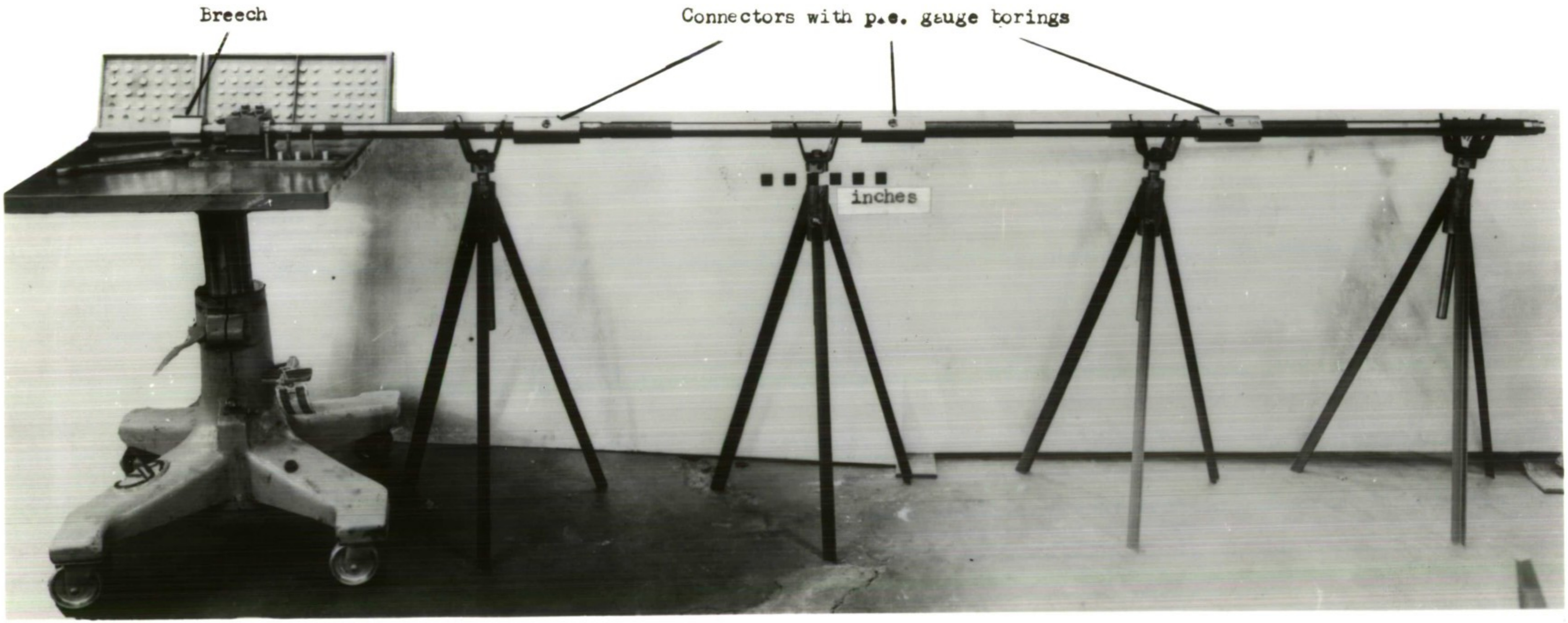


FIG.2 - General view of L.P. "Travelling Charge" Gun (assembled in Workshops)

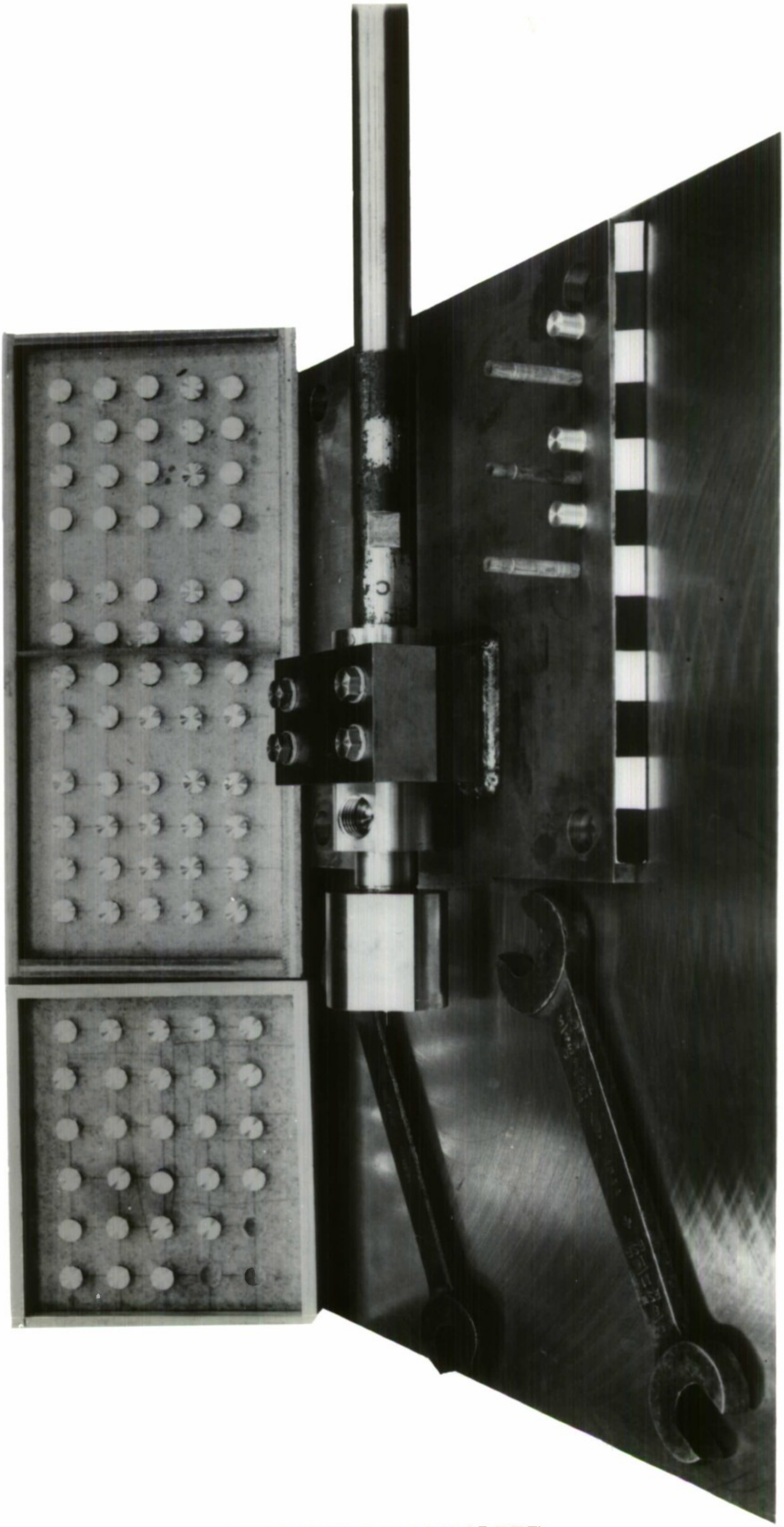

FIG.3 - "Travelling Charge" Gun
<u>Close-up view of Breech with shot and empty igniter tubes</u>

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FIG. 4

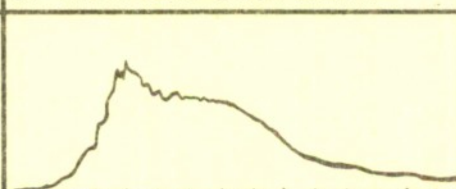
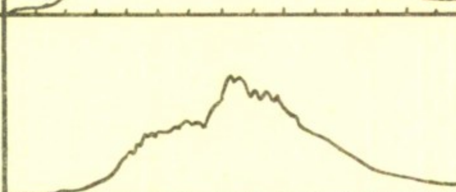
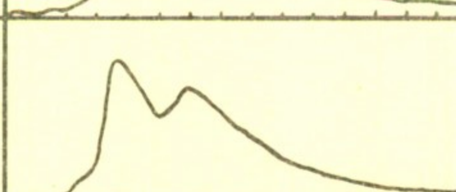
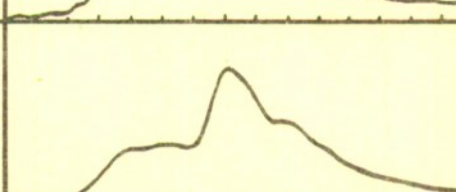
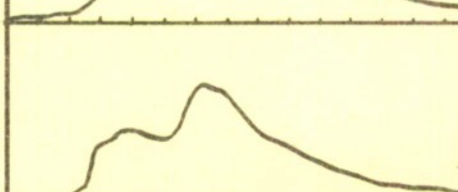
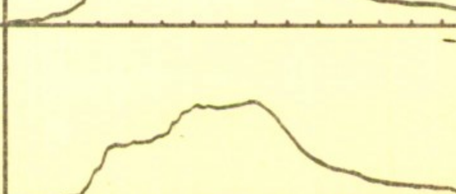
# SUMMARY OF RESULTS FOR 77 mm. FIRING 6TH MARCH 1956

GUN :- Q.F. 77 mm. No. 6583

PROPELLANT:- ISO PROPYL NITRATE NOMINAL VOL. 2400 ml.

IGNITION:- PRIMER PERC. No. 11 MK.3.

ALL SHOT 17 LB. AND COPPER BANDED.

| RD. No. | CASE VOL. ml. | CHARGE VOL. ml. | CHAMBER P-T CURVE. | $P_{MAX}$ TONS IN$^2$ | M.V. FT./SEC. | REMARKS. |
|---|---|---|---|---|---|---|
| 1 | 2390 | 2340 | N.R.-PREMATURE TRIGGERING OF RECORDING EQUIPMENT. | - | 2585 | 30 ml. ULLAGE |
| 2 | 2398 | 2348 |  | 21·7 | 2608 | |
| 3 | 2400 | 2350 |  | 21·4 | 2615 | |
| 4 | 2399 | 2299 |  | 25·7 | 2622 | 80 ml. ULLAGE |
| 5 | 2399 | 2299 |  | 23·7 | 2623 | |
| 6 | 2400 | 2300 |  | 21·6 | 2606 | |
| 7 | 2392 | 2242 |  | 22·4 | 2564 | 130 ml. ULLAGE |
| 8 | 2413 | 2263 |  | 20·1 | 2504 | |
| 9 | 2390 | 2240 |  | 17·4 | 2544 | |

~~CONFIDENTIAL DISCREET.~~

FIG. 5

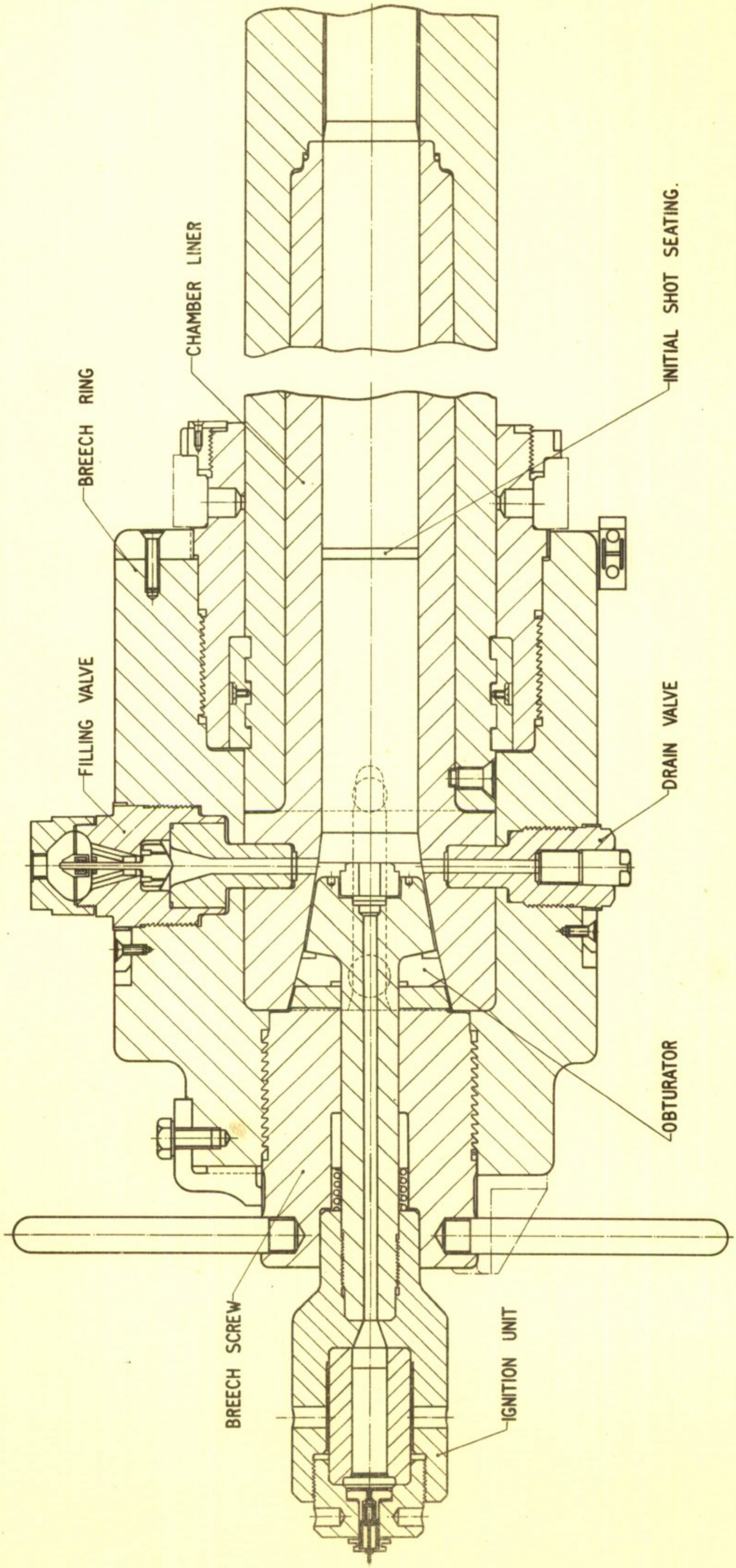



FIG. 5. 20 PR. BULK LOADED SLAVE GUN.

[dstl]

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*Knowledge Services*
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*Wilts*
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Record Summary:
Title: Guns using liquid propellants:report No 4; January - June 1956
Covering dates 1956
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) Memorandum (P) 31/56
Held by The National Archives, Kew

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